12. OCEANOGRAPHIC DATA REQUIREMENTS FOR THE DEVELOPMENT OF AN OPERATIONAL SATELLITE SYSTEM

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Ocean data acquired from future space systems will be used by space oceanographers who have been trained specifically to evaluate the unique features of the ocean surface. Through selected computer programs, these scientists will reduce the data into the frame of reference suitable for the clients -- fishermen, shippers, pollution controllers, and the like.

The space oceanographer will want data that have practical application. In particular, he will need to know the wind field and wind speed; wave systems; ocean currents -- their boundaries and speeds; turbulent features such as eddies and divergences; depth of the mixed layer (thermocline); water temperatures and their gradients; biological productivity; and fluxes of heat, moisture, and carbon dioxide.

Suitable and applicable data to satisfy these needs can apparently be acquired from earth-orbital sensor systems that will measure (a) ocean color, (b) sea-surface roughness, (c) sea-surface temperature, (d) slope of the ocean surface and (probably) of significant waves, (e) atmospheric profiles of temperature, moisture, and carbon dioxide, and (f) lunar magnitude of tide-producing forces. Some other features possibly can be measured such as phosphorescence of surface oils after excitation by ultraviolet laser beams, but neither the capability nor the utility exists at the moment.

Occasionally, because of a rare combination of extreme intensity of phytoplankton growth, atmospheric conditions, and the camera-sun angle, water-color distinctions have been photographed. Such an instantaneous event took place on October 12, 1968, when the Apollo 7 spacecraft crossed over the Gulf of California and is shown in Figure 12.1.

It is usually not imaged on color film because the shift in the blue spectrum produced by the organic constituents is very small. To resolve such subtle color differences in the ocean, sensors with band widths of 100 Ångstrom units will be required.

The precision of measurement, and spatial and temporal repetition intervals of ocean-surface data points have yet to be established with any confidence. This shortcoming exists primarily because many of the features that we now know can be sensed, as determined from photography from manned

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space flights, were previously either unknown or merely suggested by data collected in the classical manner. Consequently, we have little information about the rates at which some turbulent features form -- for example, coastal eddies and convergences. Further, although we know that major ocean currents meander, with a resulting migration of the boundaries over distances of hundreds of kilometers, we have only the vaguest concept of the pulse of such perturbations.

At this time the best estimates concerning resolution requirements are: (1) temperature to about 1° C; (2) spatial interval of 10 km^2 near islands, coasts and current boundaries, and 500 km^2 in the open ocean; (3) roughness patterns outlining ocean-surface features as small as 25 km^2 (Figure 12.2); (4) repetition intervals of 24 hours near coasts and 5 days over the opean ocean; (5) wave heights to 5 m; (6) wind speeds to 15 m/sec; (7) surface-feature resolution of 100 m; and (8) surface color resolution of 1,000 m (with 100 Ångstrom band widths).

In Figure 12.2 which was taken from an altitude of 700 km, a curling eddy of the western Gulf of Aden was visible from the Gemini XI spacecraft, September 14, 1966. The eddy was clearly outlined by the difference in roughness of the sea surface as indicated by the responding reflection of the sun. This system of turbulent flowing water, with its associated convergences, divergences, and eddies, involves an area larger than the combined states of Massachusetts, Connecticut, and Rhode Island, and is a major contributor to the biological productivity of the Gulf of Aden.

Data derived from space systems will be reduced to a suitable form by "interpretive" computer programs. The interpretation will be based on the state-of-knowledge of the real ocean and its constituents, versus the remotely sensed data. Results, therefore, will be no better than the "ground truth" program which will be conducted between now and the time of orbit.

Because of the prevailing uncertainties of the rates and magnitudes of change in particular ocean waters, the experimental space program clearly requires the rational discrimination of man. The success of an oceanographic space system that is operational will depend entirely on well-conducted, logically designed, manned-orbiting surveys that are coupled with simultaneous oceanographic cruises, judiciously undertaken to complement the orbital paths and times of the space flights. A coordinated team effort by space oceanographers at Mission Control, at field stations, and in the orbiting laboratory will be essential in the developmental program.

Personnel on oceanographic cruises that must be conducted simultaneously with the space flights, and during segments of the orbits of automated satellites (such as the Earth Resource Technology Satellite), will discriminatingly sample the ocean. Repeated measurements are required of water color, and the associated features; sea-surface roughness, as an indicator of boundaries and wind fields; water temperature, gradients across boundaries of water masses of significant qualities such as current speed, temperature, biological constituents, color and surface emissions in visual, infrared, and microwave spectral bands.

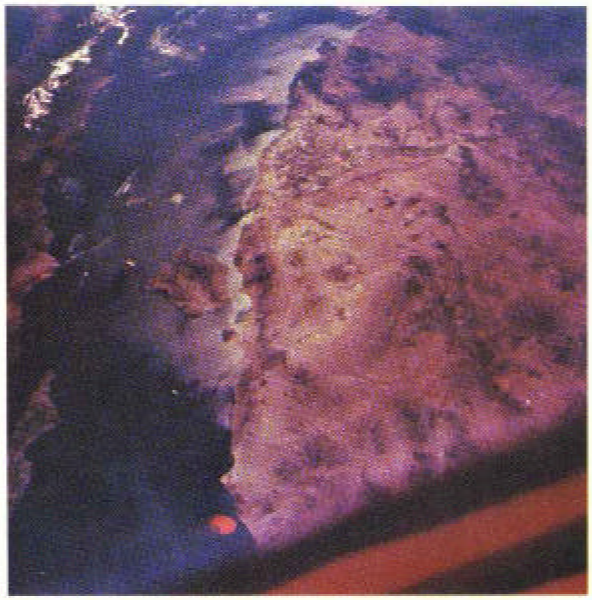

Figure 12.1 Apollo 7 over the Gulf of California

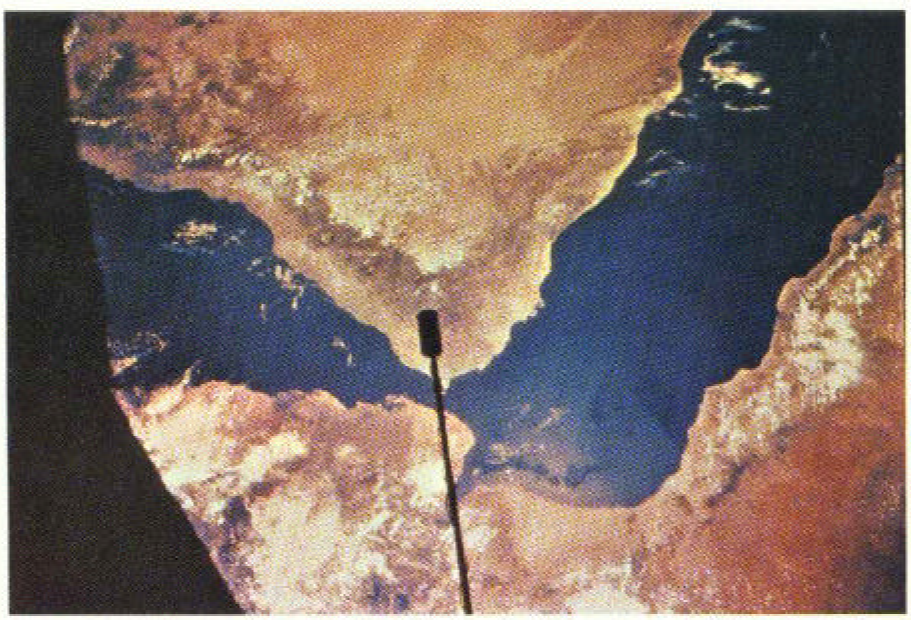

Figure 12.2 Gulf of Aden from Gemini XI, September, 1966

Information of the variations across boundaries in the ocean is virtually non-existent. Although knowledge about boundary gradients of temperature, nutrients, current speed, and turbulence has been recognized as vital to comprehension of ocean features, the invisibility of the boundaries has reduced measurements to chance.

From space, the boundaries between water masses, currents, and turbulent waters are visible mainly because of differences in sea-surface roughness. Figure 12.3 shows the wake behind Sao Tiago, Cape Verde Islands,

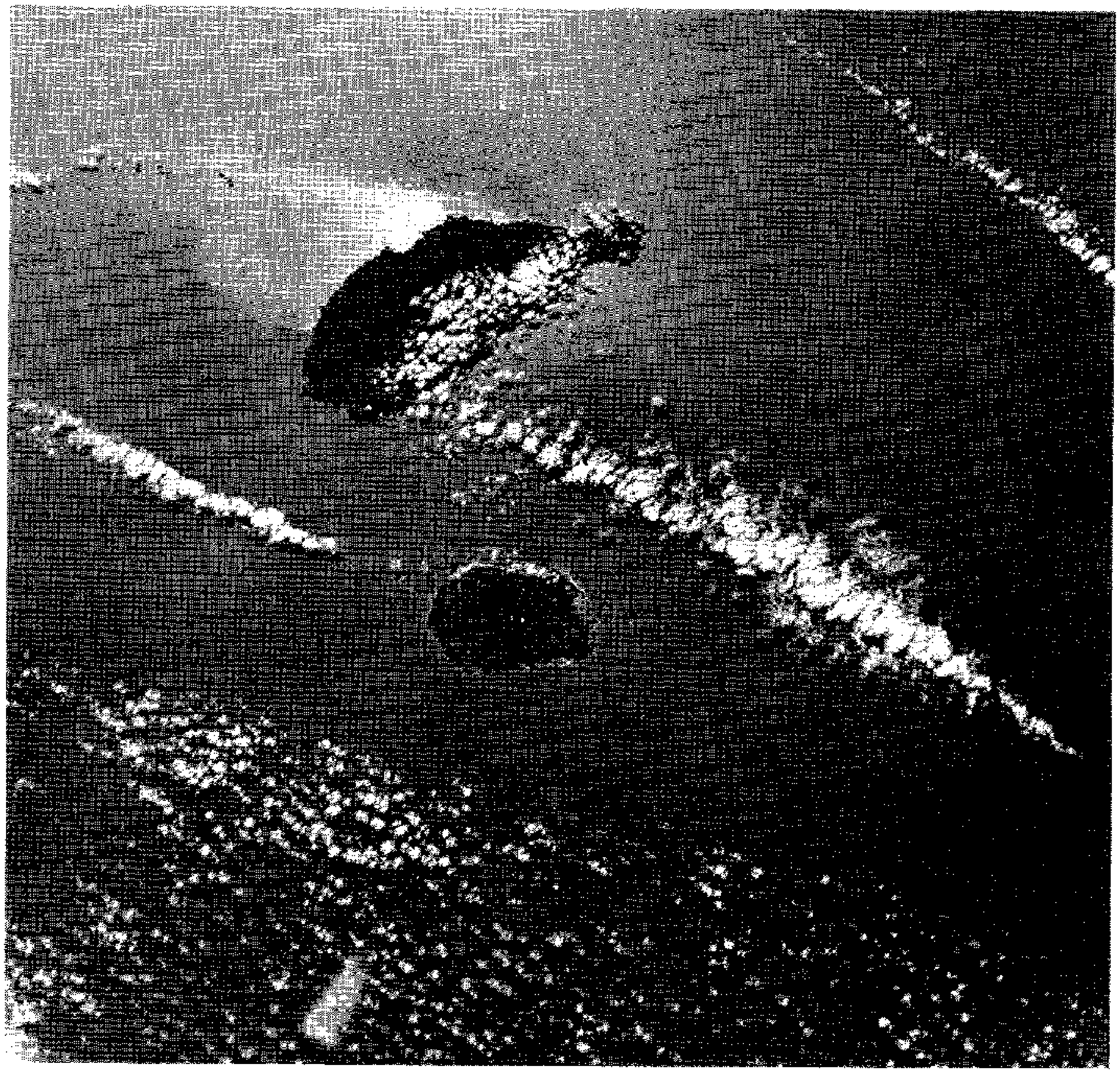

Figure 12.3 Wake behind Sao Tiago, Cape Verde Islands photographed from Apollo 9

seen in the reflection of the sun on March 9, 1969, during the Apollo 9 mision, and is an excellent example of a turbulent feature that produces sharp boundary gradients. This wake covered an area of slightly more than 2,500 km^2, and was but one of a series that extended downstream (south) at least 222 km from the island group.

The need for detailed surveys of the edges of ocean features establishes an entirely new concept -- that of boundary oceanography. Prime survey areas must be chosen where water conditions are well known from classical studies, and where the ocean contributes significantly to fisheries, oceanic productivity, or the energy budget. Ocean waters known best to the oceanographic world should be established as "calibration sites."

From these criteria, 12 ocean areas seem suitable for prime surveys, and four as calibration sites as listed in Table 12.1.

Table 12.1 -- Major Ocean Areas with Sites for Prime Surveys and Calibration Tests

Major Ocean Areas and Specific Sites	Type of Study*
Atlantic Ocean	
Caribbean-Gulf of Mexico-Gulf Stream system; Barents, North, Norwegian, Baltic, and Icelandic seas; Gibralter-Canary Island-Cape Verde upwelling zone; Benguela Current off southwest Africa	PS
North and Norwegian seas	CT
Indian Ocean	
Somali upwelling zone-western equatorial divergence-Agulhas Current; monsoon drift in the Bay of Bengal; upwelling zone northwest of Australia and the West Australian Current	PS
Mediterranean Sea	
Western basin	PS
Pacific Ocean	
Kuroshio Current system-Gulf of Alaska; equatorial system in southern Micronesian and Melanesian waters; sea off southern California; Humboldt Current	PS
Sea off southern California; waters southeast of Australia-Tasman Sea; Sea of Japan	CT

*PS -- prime surveys
CT -- calibration tests

Specific examples of areas considered for prime surveys and calibration tests are shown in figures 12.4 and 12.5.

Figure 12.4 Canary - Cape Verde Upwelling Zone from Apollo 9

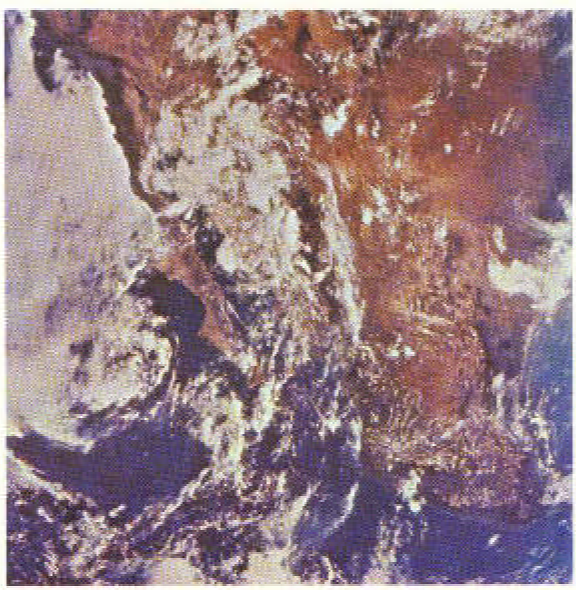

Figure 12.5 Southwestern North America from Apollo 11

In figure 12.4 the cloud-free skies neatly outlined the Canary-Cape Verde upwelling zone when the Apollo 10 astronauts viewed northwest Africa, Europe, and South America from an altitude of about 188,000 km on May 19, 1969. Such an atmospheric-oceanic view is typical wherever upwelling waters or diverging currents exist. The cloud border, which is offshore and somewhat indistinct, and the triangular clear sky area have been seen off the coasts of Somali, Western Australia, and southern California during many of the manned spaceflights. This area is one of several suitable for a prime survey.

Just after the Apollo II spacecraft was inserted into trans-lunar injection, the astronauts looked down and photographed as shown in Figure 12.5 southwestern North America from an altitude of about 8,000 km. This photograph epitomizes space oceanography more than any other, and illustrates one of several areas in which calibration tests could be completed. Motions of the marine atmosphere and the surface ocean formed the clear skies southwest of Point Conception, California. Winds that moved under the offshore inversion layer were refracted around that head-land to produce a divergence in both the lower atmosphere and the sea surface. Steadily flowing air around the Channel Islands of southern California and Guadalupe Island, Baja California, resulted in the von Kármán vortices that were especially spectacular south of Guadalupe Island.

From the somewhat warmer waters of the California Countercurrent, mild convection beneath the atmospheric inversion resulted in the vast expanse of Bénard cells. Farther south, where tropical air and waters converged, typical cumulus cloudlines were formed with distinct terminations where cold upwelling waters prevailed along the peninsula of Baja California. Within this view, nearly every oceanic action and reaction can be interpreted from one (or more) feature of the marine environment.

Such a space oceanography program requires international co-operation, coordination, and integration. This step is logical in the development of any earth-resource satellite system because orbits are necessarily "international." Beyond that, however, the ocean features that must be defined, the repetition intervals that must be ascertained, and the relationships that must be established between remotely sensed data and the beneficial "product," require oceanographic efforts greater than the existing capabilities of any single nation. With these thoughts in mind and considering the growing number of experimental orbiting systems planned for the 1970's, it seems clear that the space oceanography program fits well with the concept of an International Decade of Ocean Exploration.

Through the years of experiments that will culminate in an operational application satellite information system, the goal of the space oceanographer is to develop a model of the ocean so precise that daily predictions are made of any ocean condition significant to the interests of the clients. The role of the space system is to sense the real-time deviations from the predicted ocean. Wherever and whenever the deviations become great enough, a new base will be established for the predicted model on which the succeeding data will impact. In this way, the ocean will be viewed during each repetition interval, but computer analyses will function only from significant deviations.

I have purposely avoided discussion of the frame-of-reference information desired by the clients, that is, the practical applications and associated techniques of a space oceanographic satellite system. I can say without hesitation, however, that it will lead to that age-old dream of man -- manipulation and control of ocean environments, and the indigenous biological constituents. The magic potion that changes the dream to reality is, of course, the capability to measure continuously the ecology of the world ocean.

Technology exists for the development and implementation of earth-resource satellite systems. No breakthroughs are necessary, only the will and the effort. Apollo 11 is the best example of the perfection that can be achieved when there is the will to do it. The will and the effort must prevail for an earth-resource system. To paraphrase astronaut Michael Collins, ". . . when a fully operational application satellite information system is orbiting the earth, I want the markings on the spacecraft to be 'USA'."

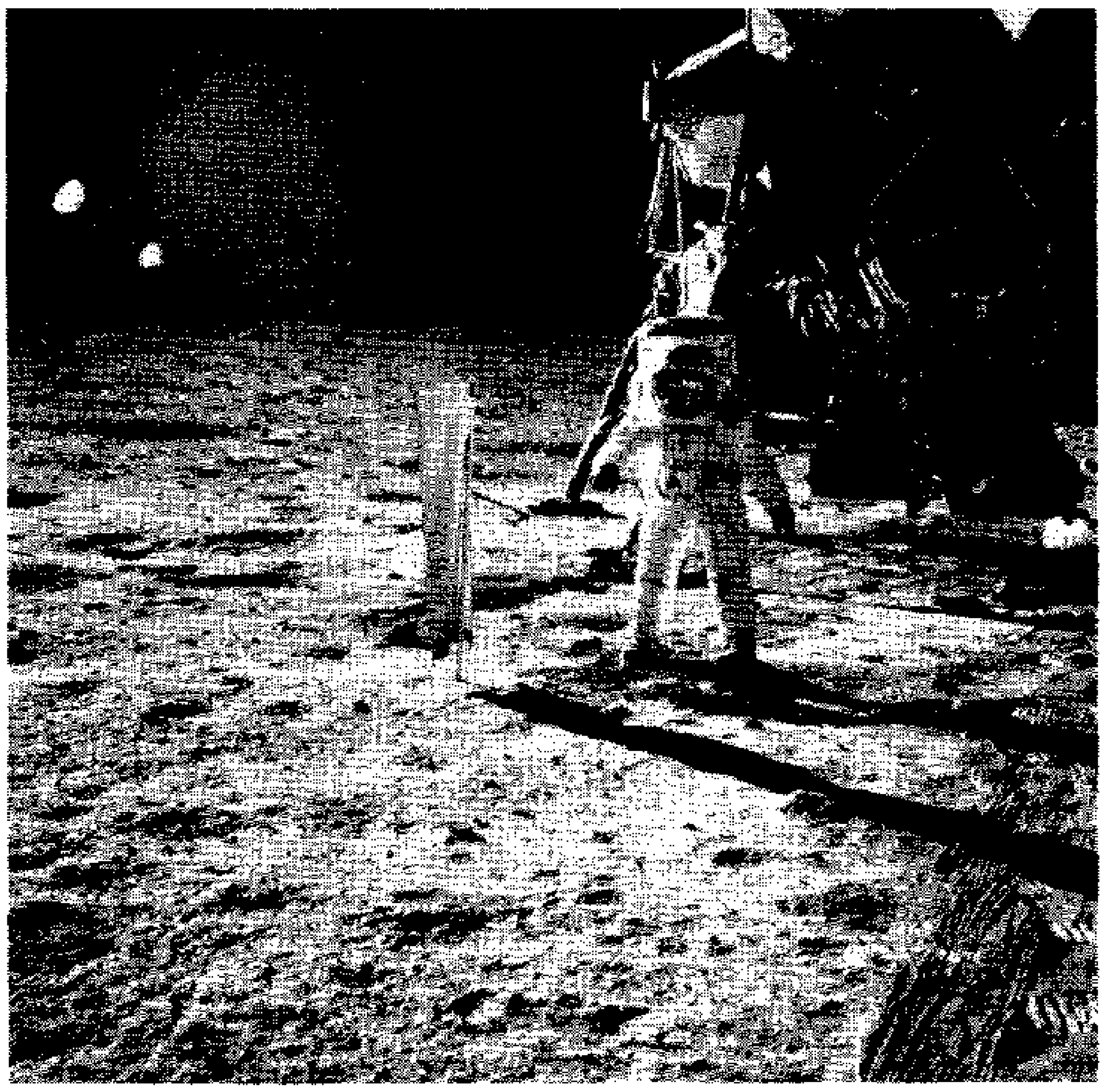

Figure 12.6. Astronaut Edwin E. Aldrin Stands Beside the Eagle, Tranquility Base, July 1969.

Suggested Readings

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